DOCUMENT RESUME

ED 250 183 SE 045 160

TITLE Water Quality Monitoring: An Environmental Studies Unit for Biology 20/30. Teacher's Guide.
INSTITUTION Alberta Environment, Edmonton. Environmental Education Resources Branch.
PUB DATE Feb 84
NOTE 43p.
PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Biology; Ecology; *Environmental Education; Field Trips; High Schools; *Laboratory Procedures; Science Education; *Science Experiments; *Secondary School Science; Units of Study; Water Pollution; *Water Quality
IDENTIFIERS *Alberta

ABSTRACT

The objective of this environmental studies unit is to establish a water quality monitoring project for high school students in Alberta while simultaneously providing a unit which meets the objectives of the Biology 20 program (and which may also be used in Biology 10 and 30). Through this project, students assist in the collection, identification, and tabulation of the invertebrate fauna of selected Alberta rivers. The project not only develops an awareness and critical understanding of the environment and current social problems (such as pollution), while contributing to the development of vocational knowledge and skills, but also represents an additional attempt by Alberta Environment to accumulate scientifically reliable information to determine areas of concern and whether remedial action is necessary. This teaching guide includes: information on materials and methods supplementary to information in the student manual; teacher and student preparation for field and laboratory activities; sampling procedures; a description of physical and chemical field studies; suggestions for further investigation; an outline for a student research paper; and a bibliography for teachers. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED250183

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)
✓ This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

TEACHER'S GUIDE

WATER QUALITY MONITORING

AN

ENVIRONMENTAL STUDIES UNIT

FOR

BIOLOGY 20/30

ALBERTA ENVIRONMENT

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
James M. Martin
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE045160

CONTENTS

INTRODUCTION 1

OBJECTIVE OF THE UNIT 3

HOW TO USE THE TEACHERS MANUAL 5

NOTE TO TEACHERS 6

MATERIALS AND METHODS

1. FIELD
   - Materials 7
   - Methods 8
     - Common Errors 9
     - Removal and Cleaning of the Net 9
     - Collecting Techniques 9
     - Additional Studies 10
   - Questions for Further Investigation 12

2. LABORATORY
   - Materials 15
   - Methods 16
     - Sample Data Sheets 18
     - List of Genera Found in Alberta Lakes 20
   - Optional Activity: Calculation of the Diversity Index 22
     - Calculation of Diversity Index (Blank) 24
     - Calculation of Diversity Index (Completed) 25

PREPARATION FOR FIELD TRIP
- Student Preparation 26
- Teacher Preparation 26

PREPARATION FOR LABORATORY WORK
- Student Preparation 28
- Teacher Preparation 28

LABORATORY PROJECT WRITE-UP
- Analysis of Data 29
- Summary for Student Laboratory Project Write-up 30
- Sample Laboratory Research Project Mark Sheet 31

ALTERNATE MACROBENTHIC INVERTEBRATE SAMPLING METHODS
- Kick Sample 32
- Hand Screen Method 32
- Surber Square Foot Sampler 32

BIBLIOGRAPHY 33

INTRODUCTION

The history of pollution is as old as society. As we are a water-based life form, societies have usually organized themselves around lakes and river, both as a supply of water and a means of disposing of wastes, thus generating the problems of water pollution. Today the exponential increase in human population and the technological and industrial complexity of our society has created unprecedented pollution concerns on a global scale. While technology has raised our standard of living, a price has been paid both in terms of the disruption of natural ecosystems and the resultant deterioration of the places in which we live.

One of the major concerns of governments is the allocation and distribution of water resources. The concept of water as a free resource is undergoing serious reconsideration; water, as all other planetary resources, is finite. Management of water requires knowledge of its quantity, quality and the impact that man's activity has in degrading or polluting that supply.

The ultimate concern of water management is how human use of water is affected. As a result, we require understanding of the physical, chemical and biological interactions, and biological measurements of stream and lake responses. One of the approaches to this is to monitor the biota of water bodies under natural conditions and in response to the discharge of effluents.

The Water Quality Control Branch of Alberta Environment has been involved in this work since 1973. However, the amount of work and number of stations required is beyond the present resources of the department. It is hoped that continually operated school monitoring stations can become an integral part of the provincial bio-monitoring network.

In 1982 and 1983 several schools in Edmonton, Calgary, Red Deer and Grand Centre began a pilot study of the Water Quality Monitoring Program. The program included the collection and identification of benthic invertebrates from selected sites on the North Saskatchewan, Bow, Red Deer and Beaver rivers by grade eleven and twelve biology students. The data collected was used to determine the impact particular effluent sources such as storm sewer discharge, sewage effluent, and wastewater effluent from industrial plants had on aquatic invertebrate life and thus help to determine changes in water quality.

Involvement in a fresh-water study of this type is ideal for the high school student. The student receives the opportunity to leave the classroom situation and experience the field work of a freshwater biologist. Theory learned in the classroom can be utilized to interpret collected data from the field. Students will be able to observe directly the relationships between living organisms and their environment, and will become aware of the present water quality in some Alberta's rivers. The class will have an opportunity to contribute statistics which could previously only be collected by a few individuals and, therefore, become part of an ongoing project. It is hoped students

will develop an understanding of the need for strict control of effluent discharge into waterways and the need for maintenance of clean supplies of water for future generations.

At the same time, teachers and students will have the opportunity to meet the following general objectives of science education as outlined by Alberta Education for grades one through twelve:

1. To develop the ability to inquire and investigate through the use of science process skills

2. To promote assimilation of scientific knowledge

3. To develop attitudes, interests, values, appreciation and adjustments similar to those ideally exhibited by scientists at work

4. To develop an awareness and understanding of the environment with positive attitudes and behaviors towards its use

5. To develop a critical understanding of those current social problems which have a significant scientific component in terms of their causes and/or their solution

6. To promote awareness of the humanistic implications of science

7. To promote an understanding of the role that science has in the development of societies and the impact of society upon science

8. To contribute to the development of vocational knowledge and skill

OBJECTIVE OF THE UNIT

The objective of this environmental studies unit is to establish a water quality monitoring project for high school students in Alberta while simultaneously providing a unit which meets the objectives of the Alberta Biology 20 program.

High school students of biology and ecology can assist in the monitoring of Alberta rivers by collecting, identifying and tabulating the benthos. The resulting information may be incorporated into a laboratory research paper as part of the core or elective component of the biology curriculum. In addition statistics regarding types and numbers of macrobenthic invertebrates will prove beneficial to Alberta Environment for studying water pollution.

Each school will be assigned a particular station or stations for the purpose of invertebrate sampling, semi-annually. Once established each school will retain the same sampling site year to year and have access to data obtained from other schools at other sites; all data will be stored on file by Alberta Environment and provide a historical record of water quality in the province.

This unit not only meets the requirements for emphasis of laboratory investigations requested by Alberta Education in the Biology 20 program but also may be used to elaborate on the following specific objectives included in the Biology 10-20-30 Interim Curriculum Guide (1983, pp. 26-29):

BIOLOGY 20

I. Ecology is the study of the interrelationships between organisms their environment.

A. Many factors are involved in ecological interrelationships.

1. Biotic factors involve the living world.

2. Abiotic factors involve the nonliving world.

3. Biotic factors and abiotic factors interact ...

a) The flow of matter through the ecosystem is cyclical.

(1) Carbon-oxygen cycle and the greenhouse effect

(2) Nitrogen cycle and nitrogenous wastes

(3) Water cycle and acid rain

b) Food chains, pyramids and webs map the flow of energy through the biotic world.

c) The introduction of pesticides into an ecosystem has serious effects on food webs.

B. Populations are composed of many individuals of the same species.

1. Populations are defined in terms of space, time and kind.

2. Populations are characterized by exponential growth patterns.

3. Limiting factors control population density.

C. The biosphere is composed of communities, ecosystems and biomes.

1. The ecosystem is the fundamental unit of the biosphere.

a) Biotic communities change predictably with time.

b) Organisms occupy a specific niche within a community.

c) Many habitats exist within a community.

2. Nutritional relationships exist within a community.

a) Symbiosis involves interaction between organisms.

b) Predatory-prey relationships exist in the biosphere.

c) Competition occurs within and between species.

3. The biosphere contain fresh water ecosystems.

a) Standing water

b) Running water

c) Humans are the major contributor to the pollution of fresh water.

4. Terrestrial ecosystems are studied in terms of biomes.

a) Canadian biomes are influences by climate.

b) Major biomes exist in Alberta.

HOW TO USE THE TEACHER'S MANUAL

This teacher's manual has been designed to aid the teacher in the implementation of a macrobenthic faura survey. Included in this manual are:

1. information on materials and methods supplementary to the information found in the student manual;

2. teacher and student preparation for the field and laboratory activities;

3. sampling procedures;

4. physical and chemical field studies are described in the Additional Studies section;

5. suggestions for Further Investigations;

6. an outline for a student research paper is provided as well as alternative research topics; and

7. a teacher's bibliography is supplementary to that list found in the student's manual.

READ THROUGH BOTH THE STUDENT AND TEACHERS MANUALS BEFORE STARTING THIS PROJECT.

NOTE TO TEACHERS

This unit should be much more than a data gathering process. Though the equipment available and site selection will in many ways dictate the main problem being studied, you should make an attempt to involve the student in an inquiry directed investigation. The student and teacher manuals include a section called Questions for Further Investigation which may assist you in developing the unit further if you so desire. The following skills can be developed through a project such as this Water Quality Monitoring unit:

1. How to state a problem for study.
2. How to consult resource information.
3. How to consult people with scientific knowledge.
4. How to make predictions.
5. How to make an hypothesis.
6. How to define the independent, dependent and controlled variables.
7. How to define the procedure and work out the sequence of steps for the procedure.
8. How to identify the needed equipment, materials and techniques.
9. How to identify safety precautions on site and using equipment.
10. How to devise a method for recording data.
11. How to collect, construct and set up apparatus or equipment.
12. How to do field work and/or perform an experiment.
13. How to record data.
14. How to obtain semi-quantitative and quantitative data by measuring, reading scales, calibrating, counting objects or events, estimating or approximating.
15. How to gather specimens.
16. How to represent the data with graphs, charts, maps, diagrams, photographs, or films.
17. How to do simple calculations with data.
18. How to use statistics to analyze data.
19. How to compare the data with initial assumptions, predictions and hypothesis.
20. How to express data in the form of a mathematical relationship.

MATERIALS AND METHODS

1. FIELD:

A. Materials:

Neil cylinder (see Student Guide for illustration)
small straight shovel (approx. one metre long)
2 nets (mesh size 210 um))
brush
bucket
plastic beaker (400 ml)
plastic funnel (approx. 15 cm in diameter) covered with netting (mesh size 200 um or smaller)
foreceps
thermometer
metre stick
labels
pencils
clipboard
vials or small glass bottles (containing 70% ethanol) (5 per student)
hip waders
rubber boots

An equipment list is provided on page 3 of the student manual.

When using the Neil cylinder as the sampling apparatus, a small shovel or other broad base device is necessary in order to loosen the bottom substrate within the cylinder. In most river bottoms large rocks are prevalent and often make the stirring procedure difficult. To facilitate the process, the larger rocks should be brushed off and then removed prior to the stirring.

Two nets per cylinder will help to speed up the actual sampling since one group of students may remove their net from the cylinder and rinse it in their buckets while another group attaches a clean net and begins sampling.

A brush for cleaning the larger rocks that are to be removed from the cylinder is optional. If the brush is not available, students should then use their hands to clean off the rocks. Some students may wish to wear rubber gloves for this purpose.

The bucket for rinsing should be as large as possible to facilitate thorough rinsing of the net and removal of attached organisms.

Numerous funnels and forceps should be provided, at least one funnel and one forcep per group of two students. Ideally, each student should have a funnel and a forcep so that separation of organisms from the water and detritus in the bucket is as rapid as possible.

It is best to have students attach the netting to the funnels in class prior to the field trip using string or elastic bands. Forceps with very fine tips are necessary since many of the organisms are small and delicate.

Labels or masking tape are necessary for recording information on the vials. Pencils are preferred over pens since ink will run when in contact with alcohol.

Each student should be provided with at least five vials containing 70% ethanol or some other adequate preservative. The vials need not exceed 2 to 3 centimetres in diameter since most of the benthic invertebrates collected will be quite small. It may be necessary to provide the student with a small plastic bag in which to store the vials.

Hipwaders are absolutely necessary for those students involved in obtaining samples with the Neil cylinder, since they are required to sample in an area 10 to 50 centimetres in depth.

Proper attire is necessary for a successful sampling day. Spring and fall weather is often cold and unpredictable. Students should be prepared for all types of weather conditions. Several layers of light but warm clothing will protect against the cold. Rubber boots are suggested instead of shoes or runners, since students will be spending most of the time on the wet and muddy riverbanks. A change of socks should be brought should an accidental soaking occur. A rainproof jacket will keep the student's clothing dry during any shower activity. Gloves or mits help to warm the hands after sampling since the water is extremely cold in the spring and fall.

The following is a list of clothing items each student should have:

- jacket
- raincoat
- several layers of light, warm shirts or sweaters
- gloves
- rubber boots, hipwaders
- extra pair of socks

B. Methods

The sampling procedure and use of the Neil cylinder is discussed on page 3 of the student manual. Students must be aware of the features of a good sampling location, that is, one in which large rocks and strong currents are avoided. It is suggested the student select a location in which the rocks are fairly small and uniform in size. Large rocks make the positioning and twisting of the cylinder and the stirring of the bottom substrate difficult. The student should select a location in an area of riffles where the current is strong enough to carry detached organisms downstream into the net. Areas of extremely strong current should be avoided since they tend to lift the cylinder and carry it downstream.

Common Errors:

Students must be made aware of several forms of sampling error. Walking directly over the substrate that is to be sampled before placing the cylinder down will dislodge organisms in the sample area and they will be swept downstream. Students should approach a location from downstream.

Error may also occur if the cylinder is lifted from the substrate during the stirring procedure as organisms may escape from the opening created at the bottom. Apply pressure to the handles of the cylinder to keep it firmly anchored.

The removal of large rocks and debris from the inside of the cylinder without first brushing to remove attached organisms is another source of error and will reduce the number of organisms collected.

Do not sample in water more than 50 cm in depth since organisms will be washed out of the top of the cylinder.

Removal and Cleaning of the Net:

After using the Neil cylinder, the net should be removed and the water allowed to drain from the bottom of the net. The student should grasp the open end of the net firmly with both hands, lower the net into the water and pull the net towards himself. Pulling the open net through the water towards the student several times will force the organisms and detritus to the bottom of the net. The net should then be turned upside-out into a large plastic bucket which is approximately 1/2 full of water. A large bucket will allow more net surface area to be exposed to the water and will ensure more efficient removal of organisms into the bucket. Students should carefully examine the net for any remaining organisms and remove them using forceps.

Collecting Techniques:

Gentle use of forceps is important. Many of the organisms such as nematode and oligochaete worms are extremely delicate and are easily damaged making subsequent identification difficult. Organisms can be easily separated from the detritus and water using a funnel covered with one layer of netting. The net covering the funnel must be wet with river water as the first beakerful of water and benthos has a tendency to run off the net instead of through it.
Students should first swirl the water in the bucket, remove a beakerful of water and slowly pour the contents through the net and funnel. Debris and organisms will remain on the netting. The debris must then be carefully sorted using the forceps and watching for any macrobenthic invertebrates. The student should watch for movement as well as body shapes and color (for example: oligochaetes of the genus Tubifex are red in color.)

Collected invertebrates should immediately be transferred to vials containing some type of preservative. The preservative will shortly cause the disappearance of any bright colors such as the red color of Tubifex. Students may wish to place these organisms in a separate vial and label the vial with information regarding color for subsequent use in identification. All vials should be labelled with the name of the site, location, date and any other information deemed useful. The vials must be closed tightly and placed in a labelled plastic bag or some form of container to transfer back to the laboratory for identification.

C. Additional Studies:

The teacher is encouraged to supplement the actual macrobenthic survey with other studies which will provide additional information regarding water quality. Such studies might include various aspects of the physical and chemical characteristics of the water such as:

a) temperature
b) dissolved oxygen (DO)
c) pH
d) alkalinity
e) hardness
f) carbon dioxide
g) phosphate (total phosphorous and soluble reactive phosphate)
h) nitrates
i) BOD (Biochemical Oxygen Demand)
j) coliform bacteria
k) depth of water
l) size of stones
m) type of bottom substrate (rocks, silt, sand)
n) productivity (amount of vegetation on bottom: subjective analysis)
o) major ions
p) rate of flow

Temperature readings may be obtained using a centigrade thermometer. Two readings should be taken in the general invertebrate sampling area: one at the surface and one at the bottom. For the surface reading, the bulb of the thermometer should be positioned directly below the surface of the water and the thermometer allowed to reach a minimum value. When obtaining a bottom temperature, the bulb of the thermometer should be positioned just above the bottom substrate for approximately one minute. The thermometer should then be removed and quickly read.

The next seven tests (b-h) may be carried out using any one of the commercial water-testing kits available such as:

Hach DR-ER Portable Engineer's Laboratory, Hach Chemical Cp., Ames, Iowa, 50010

LaMotte Model #AM-21, LaMotte Chemical Products Co.,

Chestertown, Maryland 21620

Delta Model 50 Portable Laboratory, Delta Scientific Copr., Lindenhurst, New York 11757

Each kit includes instructions on the chemical parameters outlined. Before allowing students to use these kits, where it is appropriate you must ensure that students are thoroughly aware of the safety precautions necessary for working with chemicals contained in the kits and of any hazards which may exist. The Grand River Conservation Authority has produced a slide tape presentation entitled "How To" Series which deals with the use and safety of their particular kit.

Administration Office
400 Clyde Road
Box 729 Cambridge Ontario
N1R 5W6
Tel 621-2761 Area Code 519

Biological Oxygen Demand (BOD) is a measure of the amount of molecular oxygen consumed during the decomposition of organic compounds by aerobic bacters. BOD can, therefore, be used as an indicator of water quality. Procedures for the determination of the BOD for a sample of water are outlined in several manuals such as Guide to the Study of Environmental Pollution by William A. Andrews (refer to bibliography in Student Manual).

The presence of coliform bacteria may be indicated using a lactose broth tube to which 1 cc of water sample is added. After sitting 24 hours a color change from purple to yellow or green will indicate the presence of such bacteria.

Depth of water is measured using a metre stick and should be determined at the site at which the invertebrate sample was taken. Size of stones are measured using a plastic ruler to determine the average size of the stones in the immediate invertebrate sampling area.

The type of bottom substrate (rock, stones and heavy gravel, light gravel, sand, silt or mud) should be observed and recorded.

Productivity can be estimated by examining the abundance of vegetation such as algae and other plants attached to rocks and debris. This can be measured by wet and dry weight.

The teachers should include as many additional studies as they feel appropriate for their class. Some other suggestions include the following:

1. In order to consider the invertebrate fauna of the stream with respect to their interrelationships, and the physical and chemical factors of the stream, one should consider the stream watershed as well. Students could investigate the role of the watershed on stream variation.

2. The teacher may explore the aspect that current seems to be the most important physical factor in stream or river ecology and many of the stream animals have evolved methods of protecting themselves from it. Examples are the streamlined shape of many insects, the streamlined case of the caddis-fly larvae, the books and suckers of the insects of the order Diptera, the sticky undersurfaces of the class Gastropoda, and behavioural and orientation patterns exhibited by species of invertebrates.

3. The unit can be used to investigate some ecological relationships of some of the more important invertebrates of your stream system.

4. Comparisons can also be done between species such as water beetles (coleoptera) which are carnivorous and usually found in slow or stagnant waters and water moths (Lepidoptera) which are herbivorous and found in all waters. One could begin by noting that it is the Lepidoptera that has claws on all prolegs. Is there a relationship between this peculiarity and its food habits and habitat.

A number of questions are included in the student manual in the section "Questions for Further Investigation". These questions may be used to broaden the range of the study undertaken by the student. If used as a student project, questions which would allow them to define a problem of broader scope which would incorporate the invertebrate study undertaken by the students in your class. Students could then devise a data sheet which would incorporate the variables they wish to measure in addition to the data sheet used to convey information to Alberta Environment.

Students should be encouraged to seek not only physical resources which include hard copy literature, audiovisual or software materials but also human resources. If there doesn't seem to be anyone readily available in your locale, an excellent contact source is provided by The Alberta Environmental Centre in the form of a publication Persons Involved in Environmental Research in Alberta compiled by Lee, Nevelle, and Kerr. The directory lists names of persons, with addresses and interests, involved in environmental research in Alberta. The names can be accessed by means of a comprehensive subject index. Copies of this publication are available free from:

Library
Alberta Environmental Centre
Box 4000
Vegreville, Alberta
T0B 410
Telephone: 632-6727

Questions for Further Investigation

The questions raised in this enrichment section are meant to assist the student in recognizing the role of the stream or river they are sampling within a larger ecosystem.

1. What is the problem you are studying? What are the variables involved?

2. Why did you select the area you did to sample? Why did you not pick the other side of the river? Would there be differences in what organisms would be found?

3. When numerous tributaries are entering a main stream it is important to know the watershed (boundaries of the drainage network or basin) in order to understand the relationships of nutrient cycles and chemical/physical/geological factors influencing the river. How would you determine those boundaries? For example, what are some of the advantages and disadvantages of constructing a drainage network from a topographic map?

4. What effect does current have on determining what organisms are found in the channel? Note that riffles are areas of erosion and scouring due to the faster current whereas pools are areas of slower currents and therefore areas of deposition. How could you measure the rate of flow of the current?

5. The stream flow or discharge increases to a peak following a rainstorm or snowmelt period, then decreases. What effect would this have on the organisms found in your sampling area?

6. Why did you not pick through the sand in your sampling?

7. Why did you stir the substrate to sample your area? How effective is this? What problems may arise in your sampling?

8. How can invertebrates be used as a measure of pollution? Why didn't we use fish or other large, mobile freshwater animals?

9. Since many aquatic macroinvertebrates have restricted distributions in the first and second larval instars, how would this affect your sampling?

10. Immature stages of the order Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Neuroptera, and certain Diptera are the dominant taxa in headwater streams. What differences did you find between this and your sampling area? Why might this occur?

11. Many aquatic organisms have certain traits that enable them to maintain their position and survive in rapidly flowing waters, for example, some mayflies have become dorsoventrally flattened. These mayflies are found close to the substrate where the water velocity is nearly zero even though they inhabit very rapid water. As you investigate the stream ecosystem note the variety of microhabitats available to stream organisms and adaptations made by the organisms. What relationships are apparent?

12. What relationships exist between the patchy distribution and abundance of organisms in a stream and the availability of microhabitats?

13. What types of invertebrates predominate in riffles? In pools? Which is richer in stream invertebrates, a pool or riffle?

14. What differences might you expect between invertebrates you would find much further upstream and those you would find downstream from your sampling position? Why would these differences occur?

15. Were you able to detect zooplankton and phytoplankton in your water samples? What relationships may be established accounting for the abundance or lack of each of the organisms?

16. Why would you dispose of terrestrial invertebrates not native to the aquatic habitat of your sampling area?

17. What effect would solar radiation have on your sampling area? What changes might you expect at night?

18. Construct a food web for your stream ecosystem and note the energy relationships involved.

19. What effect, if any, would temperature have on the concentrations of dissolved oxygen available in the river? What consequences would this have on the organisms found in your sampling area? What effect would a change in the heat content of a stream or river have on the types or organisms found? Remember that temperature is a measurement of the intensity, not the quantity of heat. What would be the effect of discharging heated water into your sampling area?

20. Are there relationships between concentrations of phosphorus and amounts of dissolved oxygen?

21. What does the concentration of soluble phosphate mean in terms of utilization of photosynthetic organisms?

22. What sources of nitrogen are available for your river ecosystem? How is nitrogen lost from the ecosystem?

23. The amount of dissolved salts in water is of major importance to maintenance of life. In addition to bicarbonates, carbonates, hydroxides and other minerals present in your water samples there may be moderate amounts of silica and chlorides, sulfates, and nitrates of calcium, magnesium, sodium, and potassium. How could you tell if the geochemical relationships involving these in your river have been altered?

24. The quantity and kinds of dissolved compounds present collectively shift the pH to the alkaline side of neutrality resulting in alkalinity of fresh waters. Is this observable in your sample area? What might account for a shift toward the acid side of

neutrality? How would this affect the organisms you have found in your sampling area?

25. Particulate organic matter of a given size may be a major food source whereas very little dissolved organic matter is utilized by aquatic animals directly. Does there seem to be relationships between organic matter identifiably present and the organisms you have found?

26. Photosynthetic populations in aquatic ecosystems can have photosynthetic rates, rates of nutrient utilization, and grazing rates affected by changes in species composition. What relationships are identifiable in the photosynthetic communities within your sampling area?

27. What would be the major ecological effects of sewage discharge on the stream ecosystem in your sample area? Is there any evidence of this? What conclusions might you reach using supporting evidence?

28. What components of your river or stream ecosystem are more sensitive to addition of pollutants? Why? How would you define a pollutant in terms of your sampling area?

29. What would be the advantages of discharging sewage effluents onto land rather than into streams? Would there be disadvantages?

30. What resources have you used to help you with your study? Are there other resources which may help?

2. LABORATORY:

A. Materials:

vials containing samples collected
identification key
dissecting microscope or hand lens
lamps
light microscope
slides
coverslips
distilled water
lens cleaning paper
petri dish or sorting pan
forceps
dissecting needle
data sheets
pencil
vials (containing 70% ethanol)
labels

A list of equipment is provided in the student manual. Some of the identification procedures may require a good dissecting microscope which will magnify at least 20X. A good source of illumination will aid

identification tremendously. A petri dish provides a surface on which to place organisms when using the dissecting microscope. On occasion, the identification of some of the smaller benthic invertebrates will require the use of a light microscope. Slides, coverslips and distilled water for a wet-amount are useful when the light microscope is used. Additional equipment such as forceps and dissecting needles are used for manipulation of the organism during identification.

Identification keys are included under separate cover. The key: A Guide to the Identification of Fresh-Water Invertebrates from Alberta Rivers identifies the most obvious characteristics to help the student determine the phylum, class or order to which each invertebrate belongs. In some cases identification to family could be made.

A blank Data sheet (provided in this manual) should be given to each student. Extra vials, containing preservative and labels are used for the storage of identified invertebrates.

B. Methods:

The student should identify each benthic invertebrate using the identification keys and the equipment provided. The procedure to to be followed is outlined on page 6 of the student manual.

Initially, similar organisms are grouped together using a pan large enough to permit observation of all or most organisms. To accomplish this the organisms are dumped from the vials into an enamel or plastic sorting pan, examined and those organisms which appear to be similar are physically separated from other groups of similar looking invertebrates. Each group can then be placed in a petri dish to which a small amount of water is added. The student need not cover the bottom with water since this causes the organism to shift position in the bottom of the dish each time it is moved. A small amount of water will prevent the organisms from drying out and yet allow the student to manipulate the organism without it floating out of view.

Each invertebrate should be classified using A Guide to the Identification of Fresh-water Invertebrates from Alberta Rivers. With most invertebrates identification to the level of order is possible and occasionally classification to lower taxa can be made. The student should be encouraged, however, to classify the organism only as far he feels confident of correct identification which in most cases will be to the level of order.

Smaller organisms may require the use of light microscopes. In such instances a wet-mount should be made by placing the organism on a clean slide, adding a drop of distilled water and placing a coverslip on top.

A data sheet has been prepared for student use and also for submission of collected data to Alberta Environment. It is important that information be recorded correctly. Sample data sheets are included in the student and teacher manuals for

reference. The name of the river and station should be given. Left or right bank is determined as one faces downstream.

The station number will be provided by Alberta Environment. The sample number will identify and distinguish each cylinder sample taken on each sampling occasion. If your class has taken twelve cylinder samples you will submit twelve data sheets numbered from 01 to 12. It is important that you record the number of samples taken by your class and assign a number to each sample which will be entered on the data sheet. The sample date should be completed as day, month and year. e.g. June 8th, 1982, will be recorded as 08-06-82.

As each invertebrate is identified it should be recorded under the column headed taxa name and the numbers of that animal identified should be recorded. On the List of Genera the more common species are indicated by an asterisk.
As each animal is identified it should be placed in a vial of preservative and labelled with its name, the station number and name, sample number collection date and student name(s)
When an invertebrate is found that has already been identified it should be tabulated on the data sheet opposite its name then placed in same labelled vial as the others. The identification should be continued until all aquatic invertebrates collected have been identified.

Occasionally some terestrial , semi-aquatic or even aerial invertebrates will be found in a sample. Examples of such organisms include ants, leaf-hoppers and adult flies. These organisms are not normally typical of the benthic environment and therefore, should be discarded and not included on the data sheet.

The following four pages include a completed data sheet and a blank data sheet plus a listing of genera found in Alberta rivers.

BIOLOGICAL MONITORING OF WATER QUALITY

DATA SHEET

RIVER North Saskatchewan River

STATION DESCRIPTION Groat Bridge - Left Bank SAMPLE NO. 1 of 5 SAMPLE DATE 23-04-80

STATION NUMBER 01

COMMENTS: Neil Cylinder; collected by Hampel and Moore; water temp 3°C; depth 36 cm; rocks (0.5 - 15 cm dia)

TAXA NAME	NUMBERS	TAXA NAME	NUMBERS
Nematomorpha	1		
Oligochaeta	5		
Plecoptera	6		
Ephemeroptera	2		
Baetis	15		
Trichoptera	3		
Chironomidae	3		
Corixidae	16		

BIOLOGICAL MONITORING OF WATER QUALITY

DATA SHEET

RIVER _____

STATION DESCRIPTION _____ SAMPLE NO. _____ SAMPLE DATE _____

STATION NUMBER _____

COMMENTS:

TAXA NAME	NUMBERS	TAXA NAME	NUMBERS

LIST OF GENERA FOUND IN ALBERTA RIVERS

EPHEMEROPTERA	PLECOPTERA	TRICHOPTERA	DIPTERA
Leptophlebia	Pteronarcys	*Hydropsyche	Blepharaceridae
Paraleptophlebia	Pteronarcella	*Cheumatopsyche	*Tipulidae
Habrophleboides	Taeniopteryx	*Arctopsyche	Tipula
Choroterpes	Brachyptera	Hydroptila	Antocha
Ephoron	Capnia	Agraylea	Pedicia
Ephemera	Leuctra	Ochrotrichia	Limonia
Hexagenia	Nemoura	Psychomyia	Hexatoma
Tricorythodes	Acroneuria	*Rhyacophila	Limnophilia
Caenis	Claassenia	*Glossosoma	Dicranota
*Ephemerella	Acynopteryx	Agapetus	Tanyderidae
Pseudiron	*Isogenus	Molanna	Psychodidae
Epeorus	*Isoperla	Oecetis	Culicidae
*Rhithrogena	*Alloperla	Athripsodes	Simuliidae
Stenonema		Leptocella	Chironomidae
Cinygmula		Beraea	
Cinygma		Helicopsyche	
*Heptagenia		*Brachycentrus	Ceratopogonidae
Ameletus		Micrasema	Tabanidae
Isonychia		Lepidostoma	Rhagionidae
*Baetis		Limnephilus	Empididae
Pseudocloeon			Dolichopodidae
Centroptilum			
Baetisca			

* - Denotes the more common species

LIST OF GENERA FOUND IN ALBERTA RIVERS (cont)

COLEOPTERA
(adults & larvae)

- Curculionidae
- Gyrinidae
- Haliplidae
- Chrysomelidae
- Dryopidae
- Elmidae
- Dytiscidae
- Amphizoidae

HEMIPTERA

- Mesoveliidae
- Corixidae
- Notonectidae

ODONATA

- Agrionidae
- Libellulidae
- Gomphidae
- Aeshnidae

NEUROPTERA

- Sialis

LEPIDOPTERA

- Elophila

GASTROPODA

- Physidae
- Lymnaeidae
- Planorbidae
- Ancylidae

PELYCYPODA

- Unionidae
- Sphaeriidae

NEMATOMORPHA

NEMATODA

TURBELLARIA

- Dugesia
- Polycelis

HIRUDINEA

- Glossiphonia
- Helobdella
- Placobdella
- Erpobdella
- Nephelopsis

OLIGOCHAETA

- Naididae
- *Tubificidae
- Lumbriculidae

HYDRACARINA

AMPHIPODA

- Hyallela
- Pontoporeia
- Gammarus

* - Denotes the more common species

C. Calculation of the Diversity Index

This section is an optional section which may be incorporated by the teacher. Following the identification and tabulation of macrobenthic invertebrates in a sample, the student will have information regarding the different types of organisms. Comparisons can be made between two or more sampling sites on the same river. Such comparisons can be guided by asking the following questions:

- which are the dominant species at each site? In other words, which species have the greatest proportion of the total numbers of organisms?

- which site has the greatest number of different types or taxa of organisms?

- what is the number of individuals (small, average, large) in each taxon at each site?

Natural biotic communities unaffected by man are typically characterized by the presence of a few species with many individuals and many species with a few individuals (Crossley and Bohsack, 1960; Williams, 1964; MacArthur, 1969). An unfavourable factor such as the addition of an effluent from a municipality results in changes in a macrobenthic community. For example, enriched areas of a stream or river receiving organic waste usually display a small number of taxa and a large number of individuals. By identifying taxa and quantifying the community structure, a direct comparison of communities in different areas of the river can be made. One of the simplest methods of comparing communities is the diversity index. Such indices are mathematical expressions which summarize large amounts of information about types and numbers of organisms in a community. The result is one value which may be compared to the value obtained for another community. One such diversity index, based on the Shannon-Weaver diversity index (Wilhm and Dorris, 1968) can be calculated using the following equation:.

$$H = \sum_{1}^{s} (p)(\log P)$$

where: H = diversity index
s = number of species
p = proportion of the total sample belonging to the species

The result will be a figure ranging from 0 to some value greater than 3. These values may be used to reflect the general health of the water upstream or downstream of an effluent source. Values of less than 1 (low diversity) i.e. few taxa, same with many individuals) have been obtained in areas of heavy pollution. Values from 1 to 3 (moderate diversity) may reflect areas of moderate pollution. Values exceeding 3 (high diversity i.e. many

taxa with few or many individuals) have been found in clean water areas.

The teacher and student should be aware that the diversity of a community may be affected by factors other than pollution. Students should be encouraged to identify these other factors and determine which may have affected their own data. Some of these are clearly interrelated. Factors affecting diversity index include the following:

1. Life cycles- Many stoneflies, mayflies and caddisflies actively grow during the winter, emerge as adults in the spring and their offspring avoid the high temperatures of summer by remaining as unhatched eggs.

2. Season-Spring run-off and flood conditions decrease the normal density of a population in several ways. It may sweep away many organisms except for those with efficient holdfast mechanisms. Sampling may be carried out in areas which have only recently become covered with water and into which benthic invertebrates have not yet had sufficient time to invade.

3. Type of substrate- Although sampling with the Neil cylinder should be carried out in rocky substrate, small differences may exist at a particular site. Sand, silt or mud bottoms may inadvertently be sampled to include the benthos specific to these substrates.

4. Velocity of the current- This is related to the season, type of substrate or microhabitat.

5. Food sources- Some organisms for example, feed on dead leaves and are therefore found in areas with trees. All organisms are most abundant in an area where a food source is readily available.

6. Sampling technique- Smaller individuals may be overlooked, so care taken in collection is of concern. The mesh size of the netting or improper use of the cylinder may also be involved in the loss of organisms with subsequent effects on diversity.

CALCULATION OF DIVERSITY INDEX $\bar{H} = -\Sigma_{i=1}^{S} (P_i) (\log_2 P_i)$

Taxon	No. in each Taxon	P_i	Calculation: $(P_i) \times (\log_2 P_i)$ ——— Enter the following information into a calculator: P_i log ÷ 0.301 =
Total No. of organisms			
Total No. of Taxa			

CALCULATION OF DIVERSITY INDEX $\bar{H} = -\Sigma_{i}^{s}=1 \ (P_i) \ (\log_2 Pi)$

Taxon	No. in each Taxon	P_i	Calculation: $(P_i) \times (\log_2 P_i)$ — Enter the following information into a calculator: P_i log ÷ 0.301 =
Heptagenia	2	2/54 = 0.037	0.037 x -4.757 = -0.176
Baetis	15	15/54 = 0.278	0.278 x -1.847 = -0.513
Isogenus	6	6/54 = 0.111	0.111 x -3.172 = -0.352
Hydropsyche	3	3/54 = 0.056	0.056 x -4.159 = -0.233
Corixidae	16	16/54 = 0.296	0.296 x -1.757 = -0.520
Orthocladinae	3	3/54 = 0.056	0.056 x -4.159 = -0.233
Pupae	3	3/54 = 0.056	0.056 x -4.159 = -0.233
Oligochaeta	5	5/54 = 0.093	0.093 x -3.427 = -0.319
Nematoda	1	1.54 = 0.019	0.019 x -5.718 = -0.108
			2.687
			Total of this column is your diversity index.
Total No. of organisms	54*		
Total No. of Taxa	9*		

PREPARATION FOR FIELD TRIP

A. STUDENT PREPARATION:

Prior to the field trip day it is suggested students be prepared with the following:

1. Students be acquainted with the gross identification of major taxa using specimens.

2. Students be familiar with the field and laboratory equipment and procedures. Have students read the relevant sections in their student manuals.

3. Students be equipped with appropriate clothing such as rubber boots, hipwaders, raincoat, gloves, socks, sweaters and jackets.

4. Students should assemble their personal equipment such as pencils, clipboard and any other appropriate items which the school may not be able to supply.

5. Students should prepare their vials by filling them 1/3 full of 70% ethanol (or other preservative), closing them tightly and storing them in a container or plastic bag labelled with name, date and sampling site.

6. Students should prepare their plastic funnels by covering them with netting and securing the netting using string or elastic bands.

B. TEACHER PREPARATION:

Prior to the field trip day it is suggested that teacher prepare the following:

1. Pre-visit the sampling sites, take samples, test equipment and bring in sample specimens.

2. Have the students organize into small groups. The size of the group depends upon what type of sampling the teacher wishes to carry out and whether each student is to gather all of their own data or if an exchange of data will occur. One example of how a group can be organized is as follows:

   A group could consist of 4 students who will carry out physical, chemical and benthic macro-invertebrate sampling at two sites (site A and site B). At site A, a sub-group of 2 students will carry out the physical/chemical sampling while the other sub-group of 2 students can sample the benthic macro-invertebrates. At site B, the roles are reversed. An exchange of data between the two sub-groups follows the laboratory work.

3. All necessary equipment to be supplied by the school or other sources be available, ready and in proper working conditions.

4. Provide the students with copies of field and laboratory procedures, data tables and personal equipment lists.

5. The teacher should ensure that students are aware of the field procedure and the use of equipment in the field by covering these topics in lectures and demonstrations.

PREPARATION FOR LABORATORY WORK

A. STUDENT PREPARATION:

Prior to the beginning of the laboratory procedures involving invertebrate identification, it is recommended that the student be prepared with the following:

1. Become familiar with laboratory equipment and procedures by reading these sections in their student manuals.

2. Familiarize themselves with the use of the dichotomous keys provided by reading through them and keying out some sample organisms.

B. TEACHER PREPARATION:

Prior to beginning laboratory procedures involving identification of invertebrates, it is suggest the teacher be prepared with the following:

1. All laboratory equipment be available and in proper working condition.

2. Have the students organize into groups. This is especially important if equipment, such as dissecting and light microscopes, are in limited supply or if the class is large (20 students or more). If equipment is limited, not all students will be able to identify organisms at the same time. If the class is large the teacher will find it difficult to assist more than a small number of students. An example of how a class could be organized is as follows:

   Those students who collected macrobenthic invertebrates at site A can begin identification of these organisms. Those students who collected physical/chemical data at site A can complete their calculations, complete new physical/chemical data tables, and begin reading background information pertaining to their project write-up. Following identification of all invertebrates collected at site A the roles are reversed. Those students who collected macrobenthic invertebrates at site B begin identification of these organisms while those students who collected physical/chemical data at site B complete their calculations, complete new data tables and read for background information. In other words, only one-half of the class would be working on invertebrate identification at any one time.

3. The teacher should ensure that students are aware of the laboratory procedures and the use of the dichotomous keys by covering these areas in lectures and demonstrations.

4. Provide the students with copies of laboratory procedures and data tables.

LABORATORY PROJECT WRITE-UP

Analysis of the Data

After identification of the invertebrate samples, there will be a considerable amount of information. In fact because of the number of students in the class, there is likely more data than most pollution biologists have. This enables the class to undertake a number of analyses not available under normal circumstances. Furthermore when projects have been under way for several years, you will have access to past data from your sampling locations together with data from any other schools working on the same river. The possible areas of investigation are:

1) sample reliability: comparing statistically the differences within a site
   - how great it is
   - what are the likely causes.

2) spatial variability: what are the differences between the sites
   - are they statistically significant (simple t-test or ANOVA)
   - are they restricted to certain groups of animals
   - can they be related to any effluent discharges
   - can you correlate changes in the biota with any physical or chemical changes in the river.

3) annual variability: after the establishment of your data base
   - are there annual differences at your sites
   - what groups are changing
   - does this indicate a change in water quality, i.e. is the change occurring at both sites or just downstream of an effluent.

4) biological indicators: with the large amount of information available to the students, they may also investigate the use of various biological indicator techniques.
   - community response
   - species response
   - diversity and other indices (see page 22)
   - similarity indices
   - indicator groups, etc.

References

Elliot, J.M. 1977. Some Methods for the Statistical Analysis of Sample of Benthic Invertebrates. 2nd ed. Ambleside, England, Freshwater Biological Association.

Green, Roger H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley and Sons, Toronto

SUMMARY FOR

STUDENT LABORATORY PROJECT WRITE-UP

After students have completed the proper sampling of the invertebrates and the chemical/physical properties of two selected sites the data could be organized into proper format, analyzed and interpreted in the form of a written paper. An approximate length for each section is given.

The paper format could be organized as follows:

I. INTRODUCTION
A brief description of:
Who was involved in the project,
What was done to obtain data,
Where was the sampling carried out,
When was the sampling and research accomplished
Why was the project carried out; why were invertebrates collected.
Background Information - uses of water by industry and municipalities.
- what are the discharges?
(three pages)

II. METHODS
An outline of the field and laboratory procedures.
(two pages)

III. RESULTS
This section includes the organized presentation of the data in the form of tables, charts and graphs.
(five pages)

IV. DISCUSSION
The discussion must include interpretation of the data, a critical analysis of the interpretations, comparison of results, identification of the sources of error or weakness in the design of the procedures, application of the data.
(five pages)

V. CONCLUSION

A generalized summary of the results and an expression of your own point of view regarding the data obtained.
(one page)

VI. BIBLIOGRAPHY
A complete list of all the references used, written in the correct format.
(two pages)

The student manual includes a detailed outline of what is to be included in each section. It is suggested the entire paper be no more than 20 typewritten pages in length. Information on writing a scientific paper is also included in the student manual.

SAMPLE LABORATORY RESEARCH PROJECT

MARK SHEET

Partial Mark		Comments
	Introduction	
/1	a. Who was involved in the study	
/2	b. What type of data was collected	
/1	c. Where was the sampling carried out	
/1	d. When was the data collected, analyzed and the paper written	
/5	e. Why - State the objectives of the project.	
/15	f. Background Information - uses of water - discharges - significance of each chemical test - ecology of a river community	
/25 (Total Mark)		
	Methods	
/5	Brief summary of the field and laboratory procedures.	
	Results	
/10	a. Identification of invertebrates	
/2	b. Invertebrate data tables	
/3	c. Physical/chemical data tables	
/5	d. Composite data table (comparing physical/ chemical characteristic, benthic invertebrates, of the different sites.	
/20 (Total Mark)		
	Discussion	
/15	a. Interpretation of data	
/5	b. Validity of results	
/5	c. Comparison of results with other data	
/5	d. Application of data	
/30 (Total Mark)		
/5	**Conclusion** Personal opinion of what is indicated by the research	
	The Paper	
/2	a. Format	
/5	b. English	
/2	c. Footnotes (Literature Cited)	
/1	d. Title page	
/2	e. Extra sources	
/2	f. Bibliography (Literature Cited)	
/1	g. Neatness and legibility	
/15 (Total Marks)		

ALTERNATIVE MACROBENTHIC INVERTEBRATE SAMPLING METHODS

The riffle habitat is the ideal location for the collection of benthic macroinvertebrates. A riffle is a shallow portion of a stream where the water races over the rocks and gravel creating a rippling effect. The benthos can be collected from these locations using the following sample methods:

A. KICK SAMPLE:

In this method a long-handled, D-Frame aquatic net is positioned firmly on the bottom substrate. The substrate immediately upstream of the net is thoroughly disturbed using the hands and feet for approximately two minutes. This allows the benthos dislodged to be carried downstream into the net. The net is then removed from the stream and emptied into a white enamelled pan containing a small amount of water. The invertebrates can then be easily seen against the white background as they swim or crawl out from the debris. They can be removed using forceps and transferred to vials. It must be noted, however, that this method is strictly qualitative.

B. HAND SCREEN SAMPLE:

This method is similar to the kick sample except that a hand screen is used instead of an aquatic dip net. The screen is positioned and held in the current against the substrate by one collector while the other collector disturbs the rocks and gravel on the upstream side. The dislodged organisms are carried onto the screen by the current. The screen is removed, emptied into a white enamelled pan and the invertebrates collected in the same manner described in the kick sample method. As is the kick sample, this technique also provides only qualitative data.

C. SURBER SQUARE FOOT SAMPLER:

This is a good method for quantitative collection of the macrobenthic invertebrates, but its use is restricted to water less than 30 cm in depth and in water of slow to moderate velocity. The sampler consists of two hinged frames: one supporting the net, stretched downstream which collects the invertebrates, while the other frame marks the 30 cm boundary from which the benthos is to be collected. The sampler is firmly positioned in the current and held against the substrate with the knees. The open end of the net should face upstream. Rocks and other material within the square foot boundary are carefully washed by hand to dislodge any organisms and are then discarded. Following the removal of the larger rocks and stones, the area is gently churned up with the fingers to expose burrowing forms to the current. The net is removed and again emptied into a white enamelled pan from which the organisms are removed. The net may also be emptied into a bucket half-filled with water. The water and benthos can then be poured through a net-covered funnel as outlined in the procedures for the Neil cylinder, and the organisms removed from the netting using forceps.

BIBLIOGRAPHY

Alberta Education, Biology 10-20-30 Interim Curriculum Guide, Edmonton , Alberta, 1983.

Cairns, J. Jr. and Dickson, K. L. 1971. "Sample Method for the Biological Assessment of the Effects of Waste Discharges on Aquatic Bottom-dwelling Organisms" Journal Water Pollution Control Federation Vol. 43: 755-772.

Coleman, M. J. and Hynes, H.B.N. 1970. "The Vertical Distribution of the Invertebrate Fauna in the Bed of a Stream" Limnology Oceanographer 15: 31-40

Egloff, David A. and Brakel, William H. 1973. "Stream Pollution and a Simplified Diversity Index". Journal Water Pollution Control Federation Vol. 45 No. 11: 2269-2275.

Hynes, H. B. N. 1960. The Biology of Polluted Waters University of Toronto Press, Toronto

Hynes, H. B. N. 1974. "Further Studies on the Distribution of Stream Animals within the Substratum". Limnology Oceanographer 19: 92-99

Lind, Owen T. 1974. Handbook of Common Methods in Liminology. The C V. Mosby Co., Saint Louis

MacArthur, R. H. 1969. "Patterns of Communities in the Tropics". Biol. J. Lmin. Soc.1: 19-30

MacKenthun, Kenneth M. 1966. "Biological Evaluation of Polluted Steams" Jour Water Poll Control Fed. Vol. 38: 241-247

Pennak, R. W. 1953. Freshwater Invertebrates of the United States. The Ronald Press Co., New York

Resh, Vincent H. and John D. Unzicker. 1975. "Water Quality Monitoring and Aquatic Organisms: The Importance of Species Identification." Jour. Water Poll. Control Fed. Vol. 47: 9-19.

Reynoldson, Trefor B. 1973. Macrobenthic Fauna Surveys: Old River, Bow River, Red Deer River, North Saskatchewan River. Alberta Environment, Water Quality Control Branch, Pollution Control Division, Edmonton, Alberta.

Usinger, R. L. 1973. Aquatic Insects of California. University of California Press.

Ward, H. B. and G. C. Whippel. 1959. Fresh-water Biology, 2nd ed. John Wiley and Sons, Inc., New York. (Edmondson, W. T. editor).

Warren, Charles E. 1971. Biology and Water Pollution Control. W. B. Saunders Co., Toronto.

Wetzel, Robert G. and Gene E. Likens, Limnological Analyses, W. b. Saunders Company, Toronto, 1979.

Wihm, J. L. and Dorris, J. C. 1968. "Biological Parameters for Water Quality Criteria". Bioscience 18: 447-481

Williams, C.B. 1964. Patterns in the Balance of Naure and Related Problems in Quantitative Ecology. Academic Press, New York.